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JOINT SUMMER RESEARCH CONFERENCES IN THE MATHEMATICAL  
SCIENCES (7TH) HELD. (U) AMERICAN MATHEMATICAL SOCIETY  
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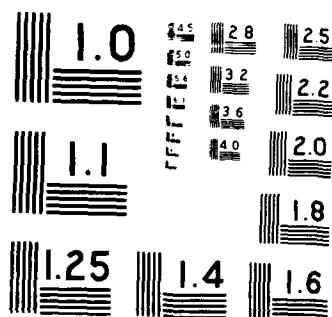
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AD-A205 952

FINAL REPORT

American Mathematical Society  
Institute of Mathematical Statistics  
Society for Industrial and Applied Mathematics

1988 Joint Summer Research Conferences in the Mathematical Sciences

NOV 14 1988 - J-1019  
Bowdoin College, Brunswick, Maine

June 11 to August 5, 1988

① DTIC  
ELECTED  
DEC 16 1988  
S A D

\*The mathematics and physics of order and disorder

\*\*\*\*Spatial statistics and imaging

\*\*Mathematical developments arising from linear programming algorithms

\*Geometric Problems in Fourier Analysis

\*Computational number theory

\*Current progress in hyperbolic systems  
Riemann problems and computations

\*Mathematical problems posed by anisotropic material

\*Geometric and topological invariants of elliptic operators

\*Elliptic genera and elliptic cohomology

\*\*\*Control theory and multibody systems

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- \* Supported by the National Science Foundation under Grant Number DMS-8613199.
- \*\* Supported by the Office of Naval Research with supplementary funding by the National Science Foundation.
- \*\*\* Supported by the National Science Foundation with supplementary travel support provided by Defense Advanced Research Projects Agency.
- \*\*\*\* Supported by the Army Research Office

## Final Report

### 1988 Joint Summer Research Conferences in the Mathematical Sciences

The Joint Summer Research Conferences were held at Bowdoin College, Brunswick, Maine from June 11 to August 5. This marks the seventh installment in the conference series begun in 1981.

The topics and organizers for the series of conferences were selected by the AMS-IMS-SIAM Committee on Joint Summer Research Conferences in the Mathematical Sciences. The following committee members chose the topics for the 1988 conferences: William B. Arveson, James Daniel, Martin Golubitsky, Ronald L. Graham, James I. Lepowsky, John R. Martin, Tilla Klotz Milnor, Evelyn Nelson, and Ingram Olkin

#### ORGANIZATION

A list of participants, programs, and reports on the distribution of travel and subsistence offered to participants is attached for each of the conferences.

#### ABSTRACTS

Abstracts of lectures given at the conferences were submitted and will appear in the November 1988 issue of the journal ABSTRACTS OF PAPERS PRESENTED TO THE AMERICAN MATHEMATICAL SOCIETY. Abstracts submitted after the deadline for the November issue will be published in the January 1989 issue.

#### PROCEEDINGS

Proceedings from the following conferences are scheduled to be published in the AMS series CONTEMPORARY MATHEMATICS.

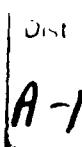
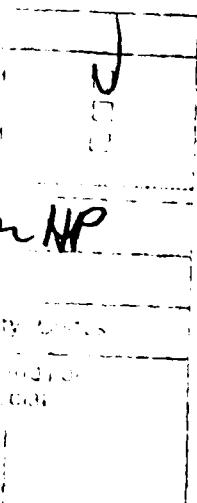
#### 1. Current progress in hyperbolic systems: Riemann problems and computations

#### OBSERVERS' REPORTS

Attached are copies of the observers reports received. These reports are written by participants who were not involved in the organization of the specific conference and are used to help in evaluating the conferences and determine where improvements might be made. Several reports have not been received as yet, and attempts are being made to obtain them.

#### SCIENTIFIC REPORTS

Attached are copies of the Scientific Reports received. These reports are written by the chairman of the organizing committee on the scientific aspects of their conference.



## CONFERENCE SITE

Bowdoin College, Brunswick, Maine

**Meeting facilities.** The Conference Office was located in the Picture Study Room on the first floor in the Visual Arts Center. All business concerning the conferences was transacted in this office.

The room was adequate, however, due to the extreme heat and humidity we experienced this summer, there were days when it was almost unbearable in the office.

The office was seldom vacuumed or the waste baskets emptied. This situation was finally brought to the attention of Anne Goodenow in the Bowdoin College Summer Office, and then the office was cleaned, but not always on a daily basis.

Major lectures and seminars were held in Kresge Auditorium and Beam Auditorium in the Visual Arts Center. The lecture rooms were equipped with overhead projectors, screens, and portable blackboards. Additional classrooms and audio visual equipment were available upon requests.

There were many complaints about the lecture rooms, especially during the weeks when the temperature went above 90 degrees. Unfortunately, the lecture rooms are not air-conditioned and there were only a few large fans available to help cool the rooms. These fans would also disappear on occasion.

Because we had to share Kresge Auditorium with the Music School there were mornings when the room was not set-up for us; this was especially true on Sunday mornings, when it was difficult to find help to set up in time for the first lecture. Finally, the Music Director and the AMS Conference Coordinator resolved the situation by preparing a schedule of times when Kresge Auditorium would be available.

Refreshments during breaks were set-up outside the Visual Arts Center during an intermission between sessions each morning and afternoon.

**Living accommodations.** Most participants residing on campus were assigned rooms in Coles Tower. Participants with families were assigned accommodations in other nearby residence halls or a hotel off campus if dormitory rooms were not available.

Participants complained that rooms were not always clean upon arrival. In some cases, participants asked to be moved to other rooms.

**Meals.** Cafeteria-style meals were served to participants and guests in the dining hall which adjoins Coles Tower. The room and board rate included three meals a day beginning with dinner on Sunday and ending with breakfast on Saturday morning. The food and service were satisfactory. The quality of the food was good, but many participants were not as impressed with the meals as they had been in 1983.

**Attendance.** There were 618 participants who registered for the conferences. Some participants were accompanied by their spouse and children.

**Conference Attendance**

1	63
2	72
3	75
4	29
5	108
6	48
7	42
8	80
9	60
10	41

An NSF questionnaire was given to each registered participant with a request to return the completed form to the Conference Coordinator. This questionnaire asked the following questions:

1. Sex?
2. U.S. Citizen
3. Ethnic/Racial Status?
4. Handicap which limits a major life activity?

The following results were compiled from the forms returned.

110 Male, 8 Female  
66 U.S. Citizens, 44 Non-U.S. Citizens  
12 Asian or Pacific Islander, 0 Hispanic, 96 white, not of Hispanic Origin  
1 With handicap, 101 Without handicap

**Social and Recreational Activities.** Participants were required to pay a \$25 social fee when registering to provide funds to cover refreshments served at daily breaks, refreshments served in the evening and a Wine and Cheese Party which was held each week.

Although no planned outings were arranged, participants were encouraged to take Tuesday afternoon as free time.

## **CONCLUSION**

Carole Kohanski, with assistance from the AMS Meetings Department staff, made all the preliminary arrangements for the conferences at Bowdoin College. Carole served as Conference Coordinator during the conferences there.

Professor James Ward, Chairman of the Department of Mathematics, Bowdoin College, served as the Local Coordinator. Anne Goodenow, in the Office of Special and Summer Programs, was extremely helpful in solving problems or answering questions. Roger Duran in the Audio Visual department was also very helpful and dependable in delivering audio visual equipment when requested.

Although the conferences seemed to be very successful, there was a general feeling that the standard of service and the facilities were not as good as they had been in 1983.

MEETINGS

NOV 07 1988

DEPARTMENT

## CONFERENCE REPORT

### MATHEMATICAL DEVELOPMENTS ARISING FROM LINEAR PROGRAMMING

BOWDOIN, JUNE 29 - JULY 5, 1988  
AMS-SIAM-IMS SUMMER RESEARCH CONFERENCE

*Jeffrey C. Lagarias*

AT&T Bell Laboratories  
Murray Hill, New Jersey 07974, USA

*Michael J. Todd*

Cornell University  
Ithaca, New York 14853, USA

This conference described current research in linear and nonlinear programming and related areas of mathematics. There has been intense development in this area, much of it in extending and understanding the ideas underlying N. Karmarkar's linear programming algorithm, which was presented in 1984. This research effort is interdisciplinary, and the conference brought together mathematicians, computer scientists and operations researchers.

The conference had 10 invited one-hour talks intended to survey topics in a wide range of areas related to linear programming. These included N. Karmarkar on the Riemannian geometry underlying interior point methods and J. Renegar on path-following methods in linear programming. K. H. Borgwardt surveyed the complexity analysis of the simplex method, and N. Megiddo the complexity of linear programming in various models of computation. S. Smale described joint work with L. Blum and M. Shub on models of computation for real numbers motivated by linear programming. D. Bayer discussed connections between linear programming and projective geometry, C. Lee described recent developments in the theory of polytopes, and Herbert Scarf described measures of the shapes of polytopes motivated by problems in integer programming. J.-L. Goffin described ellipsoid methods for general nondifferentiable optimization problems. Finally T. Bloch described completely integrable Hamiltonian flows related to least squares problems, whose solution curves fill polytopes.

There were also 26 half-hour talks which exposed the most recent research. Most of these talks arose from developments related to Karmarkar's algorithm. The topics covered can be grouped as:

- Barrier methods
- Projective methods
- Convergence proofs for linear programming
- Limiting behavior of interior-point algorithm trajectories
- Quadratic programming
- Nonlinear programming
- Integer programming
- Computational models

The most recent conference on a similar subject was *Progress in Mathematical Programming* held in Monterey, Calif. in March 1987 and chaired by N. Megiddo. Rapid progress in the subject has continued since that time, as indicated below. To put it in perspective, we first review the state of affairs as of that conference.

Karmarkar's algorithm is an interior-point method for solving linear programs. It requires having a linear program provided with a special initial starting point in the interior of the polytope of feasible solutions, called the *center*. There are two related types of algorithms, the *projective scaling algorithm*, which uses projective transformations, which Karmarkar proved to be a polynomial time algorithm, and the *affine scaling algorithm*, which uses affine transformations, and which has not been proved to converge in polynomial time (and probably doesn't). The affine scaling algorithm however has computational advantages in practice, and many of the computer implementations of "Karmarkar's algorithm" actually use affine scaling ideas. For both algorithms there is a vector field on the polytope of feasible solutions, which yields differential equations giving trajectories inside the polytope, of feasible solutions all of which go to an optimal solution. The affine and projective scaling methods have different trajectories in general, but they have one trajectory in common, the *central trajectory* or *central path*, which turns out also to be a logarithmic barrier function trajectory. Karmarkar's method, and many of the subsequent developments,

approximately follow the central trajectory. Karmarkar originally proved that a linear program (in *equality form*) in  $n$  dimensions and with input size  $L$  takes  $O(nL)$  iterations to converge and  $O(n^{3.5}L)$  bit operations in total. J. Renegar, using path-following ideas, found an algorithm requiring at most  $O(n^5L)$  iterations. By early 1987 P. Vaidya and, independently C. Gonzaga had obtained methods that followed the central trajectory requiring  $O(n^3L)$  bit operations in total. Karmarkar's algorithm also used nonlinear programming ideas involving minimizing a "potential function." Such ideas carry over to give a polynomial time algorithm for convex quadratic programming as was shown by S. Kapoor and P. Vaidya in 1987, and to a class of linear complementarity problems by Kojima, Mizuno and Yoshise.

Now we turn to results presented at the present conference. The highlight of the conference is a result of Yin-yu Ye that gives a  $O(n^5L)$  iteration algorithm using a new class of "potential functions" that apparently does not require staying close to the central trajectory. In the algorithms of Vaidya and Gonzaga one always takes "small" steps, so that such algorithms *must* take  $n^5L$  iterations to get close. The idea of Ye allows algorithms that can greedily take bigger steps and still the worst-case analysis applies. (In practical implementations one takes bigger steps than the complexity analyses allow.) Apparently Ye's analysis will extend to "projective" algorithms, too.

In early 1988 the linear programming community in the West discovered that the affine scaling algorithm was proposed in 1967 by a Soviet mathematician, I. I. Dikin, and that he gave a proof of convergence for it in 1974. R. J. Vanderbei gave an exposé of Dikin's proof of convergence, which applies under the assumption of primal non-degeneracy.

The complexity gap between affine scaling algorithms and projective scaling algorithms continues to be reduced. R. Monteiro, I. Adler and G. Resende showed that the affine scaling algorithm starting at the center and taking sufficiently small steps (but not too small) gives a provably polynomial time algorithm. Power-series approximations to the central trajectory have been observed to speed up affine scaling algorithms in practice; Monteiro, Adler and Resende

justified this theoretically by obtaining a  $O\left(n^{\frac{1}{2}\left(1+\frac{1}{r}\right)} L^{1+\frac{1}{r}}\right)$  iteration bound for  $r^{\text{th}}$  order power

series methods.

The underlying trajectories were studied by several researchers. Both Adler and Monteiro and Witzgall, Boggs and Domich proved limiting behavior of affine scaling trajectories which apply even for degenerate linear programs, where convergence of the affine scaling algorithm has not been proved. M. Asic, V. Kovacevic-Vujic and M. Radosavljevic-Nikolic analyzed the asymptotic behavior of Karmarkar's algorithm on degenerate linear programs. M. Wright described properties of logarithmic barrier trajectories.

A problem with practical implementations of interior-point algorithms is to decide when one can infer the correct set of constraints determining an optimal solution, i.e. jump out of the interior of the polytope to a vertex. D. Gay described early-stopping heuristics to do this, and K. Anstreicher gave a method using dual ellipsoids to improve performance for degenerate linear programs.

New polynomial-time algorithms for linear programming, were described by C. Roos and J.-P. Vial (path-following), J. Ding (descent method), and M. Ben-Daya and C. Shetty (barrier method).

Interior-point methods were extended to wider classes of nonlinear programs. D. Goldfarb and S. Liu obtained an  $O(n^3 L)$  algorithm for convex quadratic programming. S. Mehrotra and J. Sun gave an algorithm for solving quadratic programs *with convex quadratic constraints*, and another algorithm for smooth convex programs. F. Jarre, G. Sonnerend, J. Stoer gave a different algorithm for a quadratic problem with convex quadratic constraints and gave a proof of global convergence for their algorithm. M. Kojima described path-following methods for solving a class of *non-linear* complementarity problems. Finally N. Karmarkar proposed an interesting extension of interior point ideas and "potential functions" to solve 0-1 integer programming problems (which may be NP-complete). It uses as an auxiliary step the minimization of an arbitrary quadratic function over a sphere, which can be solved (to  $\epsilon$ -approximation) in polynomial time. It does not seem possible to give a good global running time analysis for this integer programming algorithm (not surprising since the problems are NP-complete), but Karmarkar indicates heuristics why such an algorithm might perform well on interesting classes of 0-1 integer programs, such as set covering

problems, for which good algorithms are presently not known.

R. Freund described the use of projective transformations to find weighted centers of polyhedra, and to solve linear programs. This generalizes the full-dimensional version of Karmarkar's algorithm described earlier by Bayer and Lagarias, and by Freund.

M. Todd observed a formal similarity between Karmarkar's algorithm and the Dantzig-Wolfe decomposition method (a simplex type method) for solving linear programs. He used this to propose a new variant of the simplex method.

Connections to other areas of mathematics were pursued. N. Karmarkar described a Riemannian geometry framework to describe trajectories using affine connections. He proposed a measure of the curvature of one affine connection with respect to another, for possible use in improving the worst-case complexity analysis of his original projective algorithm. There are also relations of interior-point algorithms with dynamical systems and Hamiltonian mechanics. J. Lagarias had previously showed that affine scaling trajectories are trajectories of a completely integrable Hamiltonian dynamical system, and Karmarkar had observed how to view these trajectories as a projected gradient flow for a particular Riemannian metric. At the conference T. Bloch described how the total least squares problem leads to a completely integrable dynamical system, and has recently found gradient flow interpretation of certain such systems. L. Blum described the complexity of computing Julia sets in the general real number model of computation.

Many promising directions of inquiry were described at the conference, and it seems to us that exciting developments will continue in these areas for some time. The conference was blessed with good weather and nearly perfect local arrangements.

## Conference 3

1988 Joint Summer Research Conferences

Mathematical developments arising from linear programming

June 25 to July 1, 1988

Jeffrey C. Lagarias (AT&amp;T Bell Laboratories), Co-chair

Prepared

21-OCT-1988

Budget Total:	19360
Uncommitted:	-159.57

Participant	yes	no	NSO	Travel Dom.	Travel For.	Subsist	Total	ck Req
Adler, Ilon	x			214		245	459	
Anstreicher, Kurt	x			87		222	309	
Asic, M.	x					185	185	
Balakrishnan, V.K.	x	x		50		222	272	
Barnes, Earl	x	x		50		222	272	
Bayer, David	x			150			150	
Blair, Charles	x			139		185	324	
Bloch, Anthony	x			146		222	368	
Blum, Lenore	x			274		185	459	
Borgwardt, Karl H.	x				887	222	1109	
Chandru, Vijay	x					222	222	
Choi, I.	x			50		192	242	
Ding, Jiu	x			100		222	322	
Domich, Paul D.	x						0	
Dubeau, Francois	x	x					0	
Fourer, Robert	x	x		100		222	322	
Freund, Robert	x	x		50		222	272	
Gay, David	x	x					0	
Glassman, Neil	x	x					0	
Goffin, Jean Louis	x			224		222	446	
Goldfarb, Don	x	x		50		158	208	
Goldstein,	x						0	
Gonzaga, Clovis	x				337	222	559	
Gritzmann, Peter	x				237	222	459	
Jacobs, Jonathan	x	x					0	
Jarre, F.	x				237	222	459	
Kalantari, B.	x	x				222	222	
Karmarkar, Narendra	x	x					0	
Klee, Victor	x			237		222	459	
Kojima, Masakazu	x				337	185	522	
Kovacevic-Vujcic, Vera	x			98.5		185	283.5	
Kung, Joseph	x					222	222	
Kuo, Yueh-er	x			137		222	359	
Lagarias, Jeffrey C.	x	x					0	
Lee, Carl W.	x			183.95		198.62	382.57	
Liu, S.	x					192	192	
Lustig, Irvin	x					180	180	
Marcotte, Patrice	x	x					0	
McCormick, Garth P.	x	x				222	222	
McCormick, S.	x					222	222	
Megiddo, Nimrod	x			350.5		180	530.5	
Mehrotra, Sanjay	x					224	224	
Mitchell, John E.	x	x		50		222	272	
Monteiro, R.	x			200		224	424	
Nazareth, Larry	x			202		222	424	

### Conference 3

## 1988 Joint Summer Research Conferences

## Mathematical developments arising from linear programming

International development  
June 25 to July 1, 1988

June 26 to July 1, 1988  
Jeffrey C. Lagarias (AT&T Bell Laboratories). Co-chair

Prepared

21-OCT-1988

Budget Total:	19360
Uncommitted:	-159.57

Joint Summer Research Conferences  
Mathematical developments arising from linear programming algorithms  
June 25 to July 1  
Bowdoin College  
Jeffrey C. Lagarias (AT&T Bell Laboratories), Co-Chair  
Michael Todd (Cornell University), Co-Chair

Sunday, June 26

7:30 a.m. Conference registration-Picture Study Room 102  
First floor in the Visual Arts Center

9:00 a.m. Narendra Karmarkar, The Riemannian geometry underlying the interior point algorithm for linear programming

10:30 a.m. Jim Renegar, Path-following methods in linear programming

Barrier Methods

1:30 p.m. Margaret Wright, Barrier trajectory methods for nonlinear programming

2:00 p.m. Garth McCormick, Ariela Sofer, The revised SUMT for nonlinear programming

2:30 p.m. Mohammed Ben-Daya, C.M. Shetty, Polynomial barrier function algorithms for linear programming

Convergence Proofs

3:30 p.m. R.J. Vanderbei, J.C. Lagarias, I.I. Dikin's convergence result for the affine-scaling algorithm

4:00 p.m. Clovis Gonzaga, Polynomial affine algorithms for Linear Programming

Monday, June 27

9:00 a.m. Steve Smale, Linear programming and models of computation

10:00 A.M. break

10:30 A.M. David Bayer, Linear programming and projective geometry

11:30 A.M. M. J. Todd, V. Kovalevich-Murphy, M. Freedman review  
Dikin's, Behavior of Karmarkar's method on degenerate problems

7:00 p.m. Kurt Anstreicher, Dual ellipsoids in the projective algorithm for linear programming

7:30 p.m. Mike Todd, Karmarkar as Buntz- Wolfe

Quadratic programming

8:00 p.m. Break

8:30 p.m. Don Goldfarb, D. Liu, An  $O(n^3)$  primal interior point algorithm for convex quadratic programming

9:00 p.m. Bahman Kalantari, Canonical problems for quadratic programming and projective methods for their solutions

Refreshments available in Room 2-East, Coles Tower

Tuesday, June 28

9:00 a.m. Nimrod Megiddo, The complexity of linear programming

10:30 a.m. Herbert Scarf, Shapes of polyhedra

Nonlinear programming

1:30 p.m. Masakazu Kojima, Continuation methods for a class of nonlinear complementarity problems

2:00 p.m. Florian Jarre, Gyorgy Sonnevend, Joseph Stuer, On the numerical solution of generalized quadratic programs by interior point methods

2:30 p.m. Ying-Yu Ye, A class of potential functions for linear programming

3:30 p.m. Sanjay Mehrotra, Jie Sun, A method of analytic centers for quadratically constrained convex quadratic programs

4:00 p.m. Panos M. Pardalos, Polynomial time algorithms for some classes of constrained nonconvex quadratic programs

Wednesday, June 29

9:00 A.M. Carl Lee, Recent developments in the structure of polytopes

10:30 A.M. Karl Heinz Borgwardt, Probabilistic analysis of the simplex method

### Limiting behavior

1:30 P.M. Ilan Adler, Renato Monteiro, Limiting behavior of the affine scaling continuous trajectories for linear programming problems

2:00 P.M. C. Witzgall, Paul Biegler, Paul Domich, On the convergence behavior for trajectories for linear programming

2:30 P.M. D. Gay, Early stopping heuristics that compute optional solutions for interior-point linear programming algorithms

3:30 P.M. Renato Monteiro, Ilan Adler, Mauricio Resende, A polynomial-time primal-dual affine scaling algorithm for linear and convex quadratic programming and its power series extension

### Abstract computational models

4:00 P.M. Lenore Blum, Most Julia sets are undecidable

Thursday, June 30

9:00 A.M. Anthony Bloch, Christopher Byrnes, Least squares, linear programming, and hamiltonian flows

10:30 A.M. Jean-Louis Goffin, Interior and exterior ellipsoid methods for convex non-differentiable problems defined by cutting planes

### Algorithms

1:30 P.M. Sheeram Abyankhar, Theodore Trafalis, Thomas Morin, Maximal facets of a polytope: parameterization of hyperellipsoids and their application in multiple objective optimization

2:00 P.M. C. Roos, J.-P. Vial, A simple polynomial method for linear programming

2:30 P.M. Robert Freund, Projective transformations for interior point algorithms and the center problems

### Applications to integer programming

3:30 P.M. Narendra Karmarkar, An interior-point approach to non-convex problems

4:00 P.M. George Nemhauser, Uses of linear programming in combinatorial optimization

Thursday, June 30

6:30 P.M. Roman Polyak. Methods of monotone transformation  
for nonlinear and linear programming

7:00 P.M. Problem session

List of Registered Participants  
September 16, 1998

Mathematical developments in interior point linear programming algorithms

Jeffrey C. Lagarias (AT&T Bell Laboratories), Co-Chair  
Michael Freed (Cornell University), Co-Chair

June 28 to July 1

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